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Technical Note N-1072

SEAL SYSTEMS IN HYDROSPACE, PHASE III: EFFECTS OF LONG TERM HYDROSPACE EXPOSURE ON SEAL SYSTEM INTEGRITY. 189 DAYS AT 5,900 FEET

By

James F. Jenkins and Fred M. Reinhart

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NAVAL CIVIL ENGINEERING LABORATORY
Port Hueneme, California 93041

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ABSTRACT

Long term effects of hydrospace on seals and gaskets are under investigation at NCEL (Naval Civil Engineering Laboratory). Phase III includes the evaluation of fifteen seal systems and five metallic seal flange materials after exposure to the marine environment for 189 days at a depth of 5,900 feet in the Pacific Ocean.

No seal failures due to flange corrosion or seal deterioration were noted. Galvanic anodes reduced flange corrosion. Corrosion resistant metal overlays prevented flange corrosion.

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INTRODUCTION

The high external hydrostatic pressures experienced in man's ventures into the deep ocean require pressure resistant structures of maximum integrity. Seal systems, as part of such deep ocean structures, must be reliable over the entire period of exposure in the deep ocean since periodic maintenance and repair at great depths is infeasible. Such structures, including their external seal systems, must resist not only high hydrostatic pressures but must resist, for long periods of time, the low temperatures and corrosiveness of the sea water at depth.

NCEL is determining the combined effects of material deterioration and long-term loading on the performance of seal systems in the deep ocean. To evaluate seal performance, seal model test jigs were designed and fabricated.[1] Many different types of the basic seal test jig were constructed to test the performance of several elastomeric seals in flanges and grooves of various configurations.

All seal configurations were tested for mechanical integrity under short term, long term, and cyclic hydrostatic loading.[1,2]

To determine the long term resistance of these seal systems to the deep ocean environment, seal model test jigs were exposed for 189 days at 5,900 feet of depth in the Pacific Ocean. This report presents an evaluation of the results of this exposure.

PROCEDURE

Design

The following seven basic types of seal systems were chosen for evaluation because of their use in shallow diving submersibles, deep diving submersibles, oceanographic instrumentation capsules and signaling devices, or internal pressure vessels:

a. Conventional O-Ring seal systems

b. Conventional O-Ring seal systems with anti-extrusion devices (back-up rings)

c. Dovetail groove seal systems

d. Multiple lobed (quad-ring) seal systems

e. Multiple lobed (quad-ring) seal systems with anti-extrusion devices (back-up rings)

f. Lip Seal systems

g. Elliptical groove seal systems

Systems a, b, c, d, e and f were considered for use as both a flat flange seal and an angular flange seal. System g was considered only for an angular flange seal.

Three basic seal jig types were fabricated. All jig types were designed to utilize a seal with 4.75 inches nominal diameter and 0.25 inch height made from a proprietary nitrile elastomer with Durometer A-2 hardness of 90. The seal jigs, constructed from carbon steel (AISI 1018), were cylinders 8 inches in diameter and 5 inches high fabricated from seamless tubing and hot rolled plate by welding as shown in Figures 1-4. Both flat and angular flange sealing surfaces were incorporated in this seal test jig design. Provisions for holding the seal were made in the jig cover as shown in Figures 5 and 6, the jig bottom serving as the second sealing surface. The seven groove configurations incorporated in this type jig are shown in Figures 7 through 13. Note that in all cases the minimum effective inside groove diameter is greater than the maximum inside diameter of the seal. This feature was necessary to prevent possible buckling of the seal when the jig is exposed to external pressure. The maximum clearance between sealing surfaces for both flat flange and angular flange seals was .004".

The design of the seal test jig incorporating corrosion resistant metal overlays was similar to that of the carbon steel test jig, but was modified by removal of material from the flange surfaces and deposition of corrosion resistant material on these surfaces by weld overlay techniques as shown in Figure 14. Three materials were used as corrosion resistant flange facings. Nickel-copper 400 alloy was deposited by arc welding using coated electrodes specified for overlays of nickel-copper 400 alloy on steel. Nickel-molybdenum-chromium alloy "C" was deposited by tungsten inert gas welding using hand fed bare filler wire. Nickel-chromium-molybdenum alloy 625 was deposited by metal inert gas welding using bare filler wire. All overlays were built up approximately 1/16" higher than final dimensions and subsequently machined to size. Only flat flange seal test jigs were constructed incorporating corrosion resistant metal overlays. All seal test jigs with corrosion resistant metal overlays incorporated the rectangular groove shown in Figure 7.

The seal test jigs constructed from 6061-T6 aluminum alloy were similar to those constructed of carbon steel in shape, size of seal and method of fabrication. External dimensions were, however somewhat larger. The aluminum seal test jig design is shown in Figures 15 through 17. Both flat and angular flange seals were incorporated in the aluminum seal test jigs. Rectangular seal grooves as shown in Figures 7 and 9 were used in these test jigs. The groove and seal sizes were such that the minimum inside groove diameter was larger than the maximum inside diameter of the seal in order to prevent seal buckling.

Three types of elastomeric seals were used in the seal test jigs. They are illustrated in Figure 18. The conventional O-ring seal was used in all configurations of seal test jigs with all types of seal grooves. The lobed ring seal was used in most configurations as it was reported that this seal was directly interchangeable with O-rings of

the size used in this test. The lip-type seals were used to investigate the performance of the type of seal used for many hatch and other openable flange seal applications. The lip seal required an elastomeric adhesive to hold the seal in place and to affect a seal along the lower edge and sides of the seal. The seals were lubricated with a proprietary grease, inserted in their grooves and compressed in the test jigs by tightening the cap screws in the jig cover to 25 inch-pounds of torque. This gave an initial set of ≈10% on the O-ring seal, ≈5% on the lobed ring seal (initial set for O-rings and lobed rings comensurate with seal design data), and an initial set of ≈15% on the lip type seals.

To test the effect of deep ocean environments on these three types of seals with regard to moisture absorption and hardness changes a set of one of each of the three types of seals was exposed to the sea water at depth in an uncompressed condition along with the other seal test jigs. Replicate sets of seals were exposed to sterile sea water, sterile distilled water and to air at ambient pressure and at 4°C.

The efficacy of galvanic zinc anodes in preventing or reducing the deterioration of the metallic portions of the seal systems was investigated by attaching zinc anodes to a replicate set of seal test jigs. This anode was a type ZEP style B anode with insert. The overall dimensions of this anode were 2-inch diameter and one-inch thickness and the anodes each contained approximately 350 grams of zinc. This anode gave an area ratio of 26 to 1 (steel to zinc) for the carbon steel and corrosion resistant metal overlay test jigs, and an area ratio of 29 to 1 (aluminum to zinc) for the aluminum test jigs. The anode was bolted to the test jigs and a low resistance current path between the anode and the test jig was confirmed with an ohm-meter.

The configurations of seal test jigs exposed listing test jig type, groove type, seal type and the use of anodes are given in Table 1.

The carbon steel and metal overlayed seal test jigs were sandblasted before exposure. All seal test jigs to be exposed were then placed in racks so that the jigs were electrically insulated from the racks and from one another. These racks, each containing two seal test jigs, were placed on a Submersible Test Unit so that they were located from two to ten feet above the bottom sediments during exposure. This STU with attendant emplacement and retrieval complex as described in reference 3, was emplaced at a depth of 5,900 feet approximately 80 nautical miles west-southwest of Port Hueneme, California. Details of the location of the STU and the oceanographic parameters of the emplacement site are given in Table 2.[4]

Subsequent recovery of the STU was made after 189 days of exposure. The seal test jigs were rinsed with fresh water immediately following recovery. Upon return to NCEL the jigs were removed from the racks, externally inspected, dissassembled and inspected internally, photographed, the seals removed and inspected, and the zinc anodes removed, cleaned and weighed. The uncompressed seal specimens were rinsed, dried and weighed and hardness measurements made. A like treatment was given to

the replicate sets of uncompressed seals exposed to sterile sea water, sterile distilled water, and air at ambient pressure and 4°C.

RESULTS AND DISCUSSION

External Visual Observations

Visual observation of the outside of the seal test jigs after recovery as given in table 3, showed the efficacy of zinc anodes in reducing the external corrosion of the carbon steel and aluminum test jigs as shown in Figures 19-22. Without anodes the carbon steel test jigs were covered by thick, flaky, loose red rust. With anodes the exteriors of the carbon steel test jigs were relatively clean after recovery, but quickly formed a thin layer of adherent red rust thereafter. The anodes on the carbon steel test jigs showed scattered areas of white corrosion products. The effect of anodes on the external corrosion of carbon steel test jigs with internal corrosion resistant metal overlays was the same as for the carbon steel seal test jigs without internal corrosion resistant metal overlays. The aluminum seal test jigs without anodes were covered with spots of white corrosion products which were found to cover pits up to 28 mils deep.

The aluminum seal test jigs with anodes were free from corrosion except for scattered incipient pitting.

The anodes on the aluminum test jigs were covered with a thick layer of white corrosion products. As shown in Table 4, weight losses of the zinc anodes showed no significant difference between any of the test jigs constructed from carbon steel regardless of configuration of seal or flange. The anodes from the carbon steel test jigs with corrosion resistant metal overlays showed a higher weight loss than the carbon steel test jigs without overlays. The anodes from the aluminum alloy test jigs showed a low loss of weight compared to that of the anodes from the carbon steel test jigs.

Internal Visual Observations - Leakage

Upon disassembly five seal test jigs were found to have leaked. Seal systems number 19 and 20 (Carbon Steel, angular flange, elliptical groove and O-ring seal with and without anodes) were completely full of dark green liquid under pressure and supersaturated with gas. Seal systems number 21 and 22 (Carbon Steel, angular flange, dovetail groove and lobed-ring seal with and without anodes) were three-quarters full of dark green liquid under pressure and super-saturated with gas. Seal system number 29 (Carbon Steel, angular flange, dovetail groove, lobed-ring seal and backup ring) was 1/10 full of dark green liquid under pressure and saturated with gas. The interiors of these five seal test jigs showed no red rust upon draining, but were covered with thin, dark green to black corrosion products which turned to red rust

after exposure to the atmosphere. These dark green to black corrosion products also caused the discoloration of the liquid in the seal test jigs and was subsequently found to be ferric oxide (FeO). Since upon cleaning, these five seal test jigs showed no corrosion in the seal groove or seal mating surface under the seal, the failures were attributed to mechanical failure, not failure from flange deterioration. Failure of seal systems number 19, 20, 21 and 22 were attributed to poor seal design as they had low initial seal set. Failure of seal system number 29 was attributed to localized extrusion of the back-up ring at a back-up ring defect (poor splice).

All other seal systems were found to be, upon disassembly, completely free of liquid or any evidence of leakage.

Internal Visual Observations - Flange Corrosion

Corrosion of the seal flanges and grooves of the carbon steel seal jigs, without overlays, which did not leak was found to extend only to the outer edge of the seal ring. The extent of corrosion ranged from general rusting to a few spots of discoloration. The amount of flange and groove corrosion on the carbon steel test jigs was independent of seal type and dependent only on the clearance between flange faces and the presence or absence of galvanic protection (anodes). Figures 23 through 26 show, in order, from most corroded to least corroded the dependence of the extent of flange corrosion on clearance between flange faces and presence or absence of galvanic protection. The larger the clearance between the flange faces the more severe the corrosion. Galvanic protection lessened the amount of corrosion of test jigs with both wide and narrow flange face clearances. Figure 23 shows an angular flange seal jig without an anode with rusting up to the seal, but no corrosion underneath or inside the seal. Figure 24 shows a similar seal test jig with an anode and the benificial effect of galvanic protection as evidenced by the lesser amount of flange corrosion. Figure 25 shows the extent of corrosion found on a flat flange carbon steel seal jig without galvanic protection and shows the beneficial effect of the narrow gap between flange faces, as found in all flat flange seal jigs except those with lip seals, in reducing flange corrosion. This beneficial effect is only present with deep crevices and for steel flanges such as found in this test. The surfaces inside such deep crevices are exposed to the sea water per se for only a short time. Initial corrosion in the gap soon depletes the dissolved oxygen in the sea water within the crevice and this oxygen is not replaced due to the slow diffusion of oxygen rich sea water into the crevice from outside. The oxygen poor sea water is not as aggressive toward the steel as is the oxygen rich sea water outside.[5] The differential aeration cell corrosion, or crevice corrosion, usually associated with such a difference in dissolved oxygen content was not noted in this test. This lack of crevice corrosion was attributed to the relative immunity of steel to such attack in the deep ocean[5] and to

electrical resistance effects found within deep crevices.[6] The flange faces with wide gaps such as found on all angular flange seal jigs were exposed to essentially the same conditions as the outside surfaces and corroded to nearly the same extent. Figure 26 shows the extent of corrosion on a flat flange carbon steel seal jig with galvanic protection. Only a few areas of light rust on the outside edge of the flange is evident. This shows the efficacy of galvanic protection in reducing flange corrosion especially at the edge of crevices.

The carbon steel seal jigs with corrosion resistant metal overlays showed no corrosion of the overlaid flange faces or grooves for any of the overlay materials both with and without galvanic protection with zinc anodes and caused no galvanic corrosion of the steel flange material. Figure 27 shows a flat flange carbon steel seal jig with Ni-Cu 400 alloy overlay without galvanic protection.

The corrosion of the seal flanges and grooves of the aluminum seal jigs was, like that of the carbon steel test jigs, limited to the areas outside the seal. The extent of the corrosion ranged from dark etching with scattered white corrosion products as found on the angular flange seal jigs without galvanic protection to no visible attack as found on the flat flange seal jigs with galvanic protection. Figures 28-31 show, in order from the most corroded to the least corroded, the dependence of the extent of flange corrosion of the aluminum test jigs on the clearance between flanges and the presence or absence of galvanic protection. As was the case for the carbon steel test jigs, the corrosion of the flange faces was more severe when the clearance between the flange faces was large. Galvanic protection also lessened the amount of corrosion of the flange faces for both wide and narrow flange face clearances. Figure 28 shows an angular flange seal test jig without an anode with white corrosion products and dark areas of tarnish. Figure 29 shows a similar test jig with an anode showing the efficacy of galvanic protection in reducing corrosion of the seal flanges. Figure 30 shows a flat flange seal test jig without an anode showing a small amount of etching on the flange faces up to the seal area. Figure 31 shows the absence of noticeable corrosion on a flat flange seal jig with galvanic protection showing the efficacy of galvanic protection in reducing corrosion of the seal flange faces.

Seal Condition After Exposure

The seals exposed to the sea water were inspected visually for damage. The O-ring and lobed ring seals showed no external evidence of damage in any of the configurations tested. The lip seals showed extrusion of the elastomeric adhesive used to secure them in their grooves as was noted during mechanical and cyclic loading tests,[1,2] but suffered no visible damage. The elastomeric back-up rings were found to be extruded up to 1/16-inch in some cases. In one case as shown in Figure 32 the back-up ring had failed at a poor splice and was the only leakage attributed to seal damage.

Comparison of the weight gain of the uncompressed seal specimens exposed to the deep ocean with the weight gain of companion specimens

exposed to sterile sea water, sterile distilled water and to air at reduced temperature (4°C) and ambient pressure as given in Table 5, showed that the specimens exposed to the sterile distilled water absorbed the most water, the specimens exposed to the sterile sea water at ambient pressure absorbed an intermediate amount of water, and the specimens exposed to the deep ocean absorbed the least amount of water. The difference in absorption between the specimens exposed to sterile sea water and sterile distilled water can be attributed the face that sea water and distilled water are non-isotonic and therefore develop different osmotic pressures in the elastomeric seals. The lower absorption of the specimens exposed to the high pressure environment can be attributed to the closing of pores in the material by pressure thus decreasing the amount of water the material can absorb.[7] No significant change in hardness of the seals was noted.

SUMMARY

In order to determine the effects of the deep ocean environment on seal systems, twenty seal system types were exposed at a depth of 5,900 feet in the Pacific ocean for 189 days. Seal systems utilizing carbon steel, 6061-T6 aluminum, or carbon steel with welded overlays of corrosion resistant metals; nickel-copper 400, nickel-molybdenum-chromium alloy "C" or nickel-chromium-molybdenum alloy 625 as flange faces were tested. Seal systems utilizing three types of elastomeric seals; O-rings, lobed rings and lip seals were tested. The efficacy of galvanic protection in preventing or reducing flange deterioration was determined by the attachment of zinc anodes to a replicate set of seal system test jigs. Moisture absorption of unloaded seals exposed to the deep ocean was also determined.

After exposure, three seal systems were found to have failed by leakage. This leakage was attributed to mechanical failure rather than to the effects of environmental deterioration. Although the carbon steel test jig flanges corroded, this corrosion was less severe for flanges with very narrow crevices and was reduced considerably by galvanic protection. The 6061-T6 aluminum seal test jig flanges also corroded, but to a lesser extent than the flanges of the carbon steel seal test jigs. The extent of the flange corrosion on the aluminum test jigs was less when the crevice between the flanges was small and was also reduced by galvanic protection. The seal flanges utilizing corrosion resistant metal overlays were uncorroded after exposure.

Deterioration of the elastomeric seals was by mechanical damage. The elastomeric adhesive used to hold the lip seals in place was found to have extruded but did not cause leakage. Leakage was caused however, when an elastomeric back-up ring failed at an improperly fabricated splice. The elastomeric back-up rings used in other seal systems in this test were all extruded to some degree, but this did not necessarily result in leakage. Moisture absorption of the unloaded

seals exposed to the deep ocean was less than the moisture absorption of replicate sets of seals exposed to sterile sea water and sterile distilled water at deep ocean temperatures but at ambient atmospheric pressure.

CONCLUSIONS AND RECOMMENDATIONS

With proper attention to mechanical seal design for external pressure, static seals can function reliably for periods of at least 189 days of exposure to a deep ocean environment similar to that found at a site 5,900 feet deep off the coast of Southern California. Carbon steel and 6061-T6 aluminum seal seats are suitable for use in this environment for this period without protection from the corrosiveness of the environment. Longer term exposures in the environment may be possible for these unprotected seal flange materials, but protection of the surfaces by galvanic protection of both the aluminum and carbon steel is recommended. However, in order to secure maximum reliability of seal systems over long periods of exposure to the deep ocean environment, corrosion resistant overlays of nickel-copper 400 or preferrably nickel-molybdenum chromium alloy "C" or nickel-chromium-molybdenum alloy 625 are recommended. These conclusions and recommendations are onlv for static seal systems exposed to hydrostatic - one time loading - in a deep ocean environment similar to the one to which the seal systems in this test were exposed.

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Table 1. Test Jig Configurations Exposed

Seal System Type Number	Number Exposed	Material	Overlay	Flange Type	Groove Type Figure #	Seal Type	Anode
1	2	Steel	None	Flat	7	0-ring	No
2	2	"	"		"	"	Yes
3	1	"	"	"	"	lobed ring	No
4	1	"	"	"	"	"	Yes
5	1	"	"	"	"	lip seal	No
6	1	"	"	"	"	"	Yes
7	2	"	"	Angular	9	0-ring	No
8	2	"	"	"	"	"	Yes
9	1	"	"	"	"	lobed ring	No
10	1	"	"	"	"	"	Yes
11	1	"	"	"	"	lip seal	No
12	1	"	"	"	"	"	Yes
13	1	"	"	Flat	11	0-ring	No
14	1	"	"	"	"	"	Yes
15	1	"	"	"	"	lobed ring	No
16	1	"	"	"	"	"	Yes
17	1	"	"	Angular	12	0-ring	No
18	1	"	"	"	"	"	Yes
19	1	"	"	"	"	lobed ring	No
20	1	"	"	"	"	"	Yes
21	1	"	"	"	13	0-ring	No
22	1	"	"	"	"	"	Yes
23	1	"	"	Flat	8	0-ring & backup	No
24	1	"	"	"	"	"	Yes
25	1	"	"	"	"	lobed ring & backup	No
26	1	"	"	"	"	"	Yes
27	1	"	"	Angular	10	0-ring & backup	No

(cont'd)

Table 1. Test Jig Configuration Exposed (cont'd)

Seal System Type Number	Number Exposed	Material	Overlay	Flange Type	Groove Type Figure #	Seal Type	Anode
28	1	Steel	None	Angular	10	O-ring & backup	Yes
29	1	"	"	"	"	"	No
30	1	"	"	"	"	lobed ring & backup	Yes
31	1	"	Ni-Cu 400	Flat	7	"	No
32	1	"	"	"	"	O-ring	Yes
33	1	"	Ni-Mo-Cr"C"	"	"	"	No
34	1	"	"	"	"	"	Yes
35	1	"	Ni-Cr-Mo 625	"	"	"	No
36	1	"	"	"	"	"	Yes
37	1	Aluminum	None	Flat	7	"	No
38	1	"	"	"	"	"	Yes
39	1	"	"	Angular	9	"	No
40	1	"	"	"	"	"	Yes

Table 2. STU Location and Bottom Water Characteristics

Lat.N	Long W	Depth. Ft	Temp ^oC	Oxygen ml/1	Salinity ppt	pH	Current Knots Avg	Eh mv
33^o51	$120^o35'$	5,900	2.257	1.629	34.602	7.423	0.03	178

Table 3. Visual Observations of Seal Test Jigs after Exposure

Seal System Type Number 1/	Leakage	Outside	Flange	Groove	Seal	Anode Loss (%)
1a	None	Loose Flaky Red Rust	Lt. Rust outer edge	N.C 2/	N.D. 3/	---
1b	"	"	"	"	"	---
2a	"	Lt. 4/ Red Rust	N.C.	"	"	33%
2b	"	"	"	"	"	33%
3	"	Loose Flaky Red Rust	Lt Staining	"	"	---
4	"	Lt. Red Rust	N.C.	"	"	30%
5	"	Loose Flaky Red Rust	Lt. Rust (large gap)	"	"	---
6	"	Lt. Red Rust	Spots of Rust	"	"	33%
7a	"	Loose Flaky Red Rust	Rust to edge of bevel.	"	"	---
7b	"	"	"	"	"	---
8a	"	Lt. Red Rust	Lt. Rust to edge of bevel	"	"	35%
8b	"	"	"	"	"	30%
9	"	Loose Flaky Red Rust	Rust to edge of bevel	"	"	---

Table 3. Visual Observations of Seal Test Jigs after Exposure (cont'd)

Seal System Type Number 1/	Leakage	Outside	Flange	Groove	Seal	Anode Loss (%)
10	"	Lt. Red Rust	Lt. Rust to edge of bevel	"	"	32%
11	"	Loose Flaky Red Rust	Heavy Rust to bevel	"	"	---
12	"	Lt. Red Rust	Lt. Rust to edge of bevel	"	"	31%
13	"	Loose Flaky Red Rust	Lt. Rust at edges	NC	ND	---
14	"	Lt. Rust	NC	"	"	33%
15	"	Loose Flaky Red Rust	Lt. Rust some spots	"	"	---
16	"	Lt. Rust	NC	"	"	32%
17	"	Loose Flaky Red Rust	Flaky Rust to bevel	"	"	---
18	"	Lt. Rust	Lt. Rust some spots	"	"	35%
19	850 ml (full)	Loose Flaky Red Rust	Flaky Rust to bevel	"	"	---

Table 3. Visual Observations of Seal Test Jigs after Exposure (cont'd)

Seal System Type Number 1/	Leakage	Outside	Flange	Groove	Seal	Anode Loss (%)
20	850 ml (full)	Lt. Rust	Lt. Rust some spots	"	One area of extursion 1/32"	30%
21	700 ml	Loose Flaky Red Rust	Flaky Rust to bevel	"	ND	---
22	450 ml	Lt. Rust	Lt. Rust some spots	"	"	35%
23	None	Loose Flaky Red Rust	Lt. Rust edge of flange	"	"	---
24	"	Lt. Rust	"	"	Back-up extruded up to 1/32"	---
25	"	Loose Flaky Red Rust	"	"	Slight extrusion of Back-up ring	---
26	"	Lt. Rust	"	"	Back-up extruded up to 1/16"	34%
27	"	Loose Flaky Red Rust	Flaky Rust to bevel	NC	ND	---
28	"	Lt. Rust	Lt. Rust to bevel	"	"	33%
29	75ml	Loose Flaky Red Rust	Flaky rust to bevel	"	Back-up extruded up to 1/32"	---

Table 3. Visual Observations of Seal Test Jigs after Exposure (cont'd)

Seal System Type Number [1/]	Leakage	Outside	Flange	Groove	Seal	Anode Loss (%)
30	"	Lt Rust	Lt Rust to bevel	"	ND	36%
31	"	Loose Flaky Red Rust	NC	"	"	---
32	"	Lt. Rust	"	"	"	36%
33	"	Loose Flaky Red Rust	"	"	"	---
34	"	Light Rust	"	"	"	38%
35	"	Loose Flaky Red Rust	"	"	"	---
36	"	Light Rust	"	"	"	33%
37	"	WCP[5/] with pitting	Etching	"	"	---
38	"	NC	Staining	"	"	5%
39	"	WCP with pitting	light-WCP no pits	"	"	---
40	"	NC	Staining	"	"	14%

Table 3. Visual Observations of Seal Test Jigs after Exposure (cont'd)

1. System Type Numbers refer to Table 1
2. N.C. - No Corrosion
3. N.D. - No Damage
4. Lt. - Light
5. WCP - White Corrosion Products

Table 4. Weight losses of zinc anodes

	Carbon Steel		Overlaid Carbon Steel	Aluminum
	Flat Flange	Angular Flange		
Wt. loss (avg)	120gms 405mdd[1]	121gms 400mdd[1/]	131gms 440mdd[1/]	35gms 104mdd[1/]

[1/]Milligrams of zinc per square decimeter of steel or aluminum protected per day.

Table 5. Moisture Absorption & Hardness Change

Specimen	Weight Change (mg)	Hardness Change (Durometer A)
Control (Air-4°C)		
O-Ring	+22.0	+1
Lobed Ring	+17.1	0
Lip Seal	+46.7	-1
Sterile Distilled Water (Lab-4°C)		
O-Ring	+118.9	-1
Lobed Ring	+120.1	0
Lip Seal	+201.0	+1
Sterile Sea Water (Lab-4°C)		
O-Ring	+93.7	0
Lobed Ring	+65.8	0
Lip Seal	+182.1	+1
In Situ		
O-Ring	+72.8	0
Lobed Ring	+39.8	+1
Lip Seal	+178.4	0

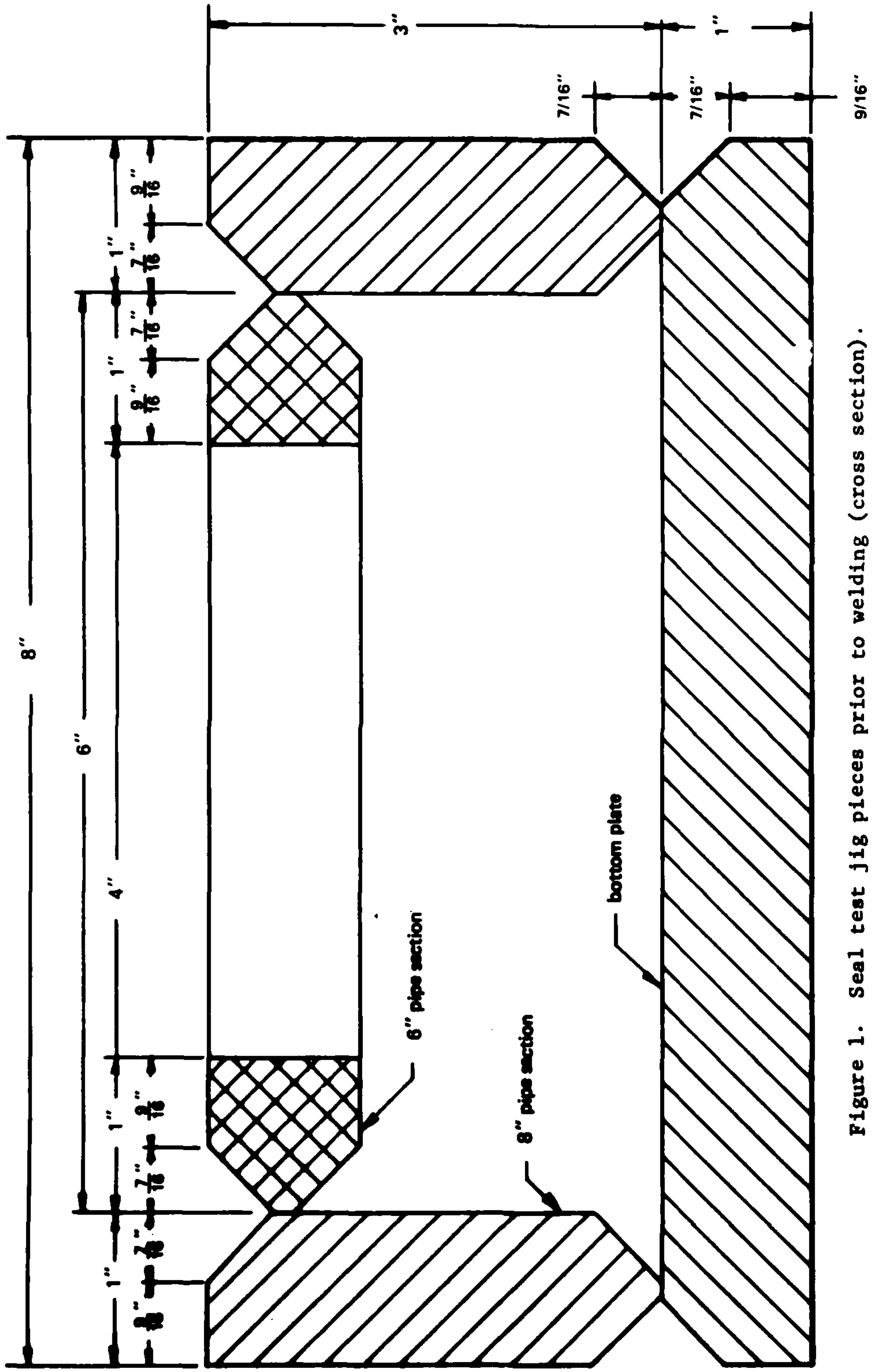

Figure 1. Seal test jig pieces prior to welding (cross section).

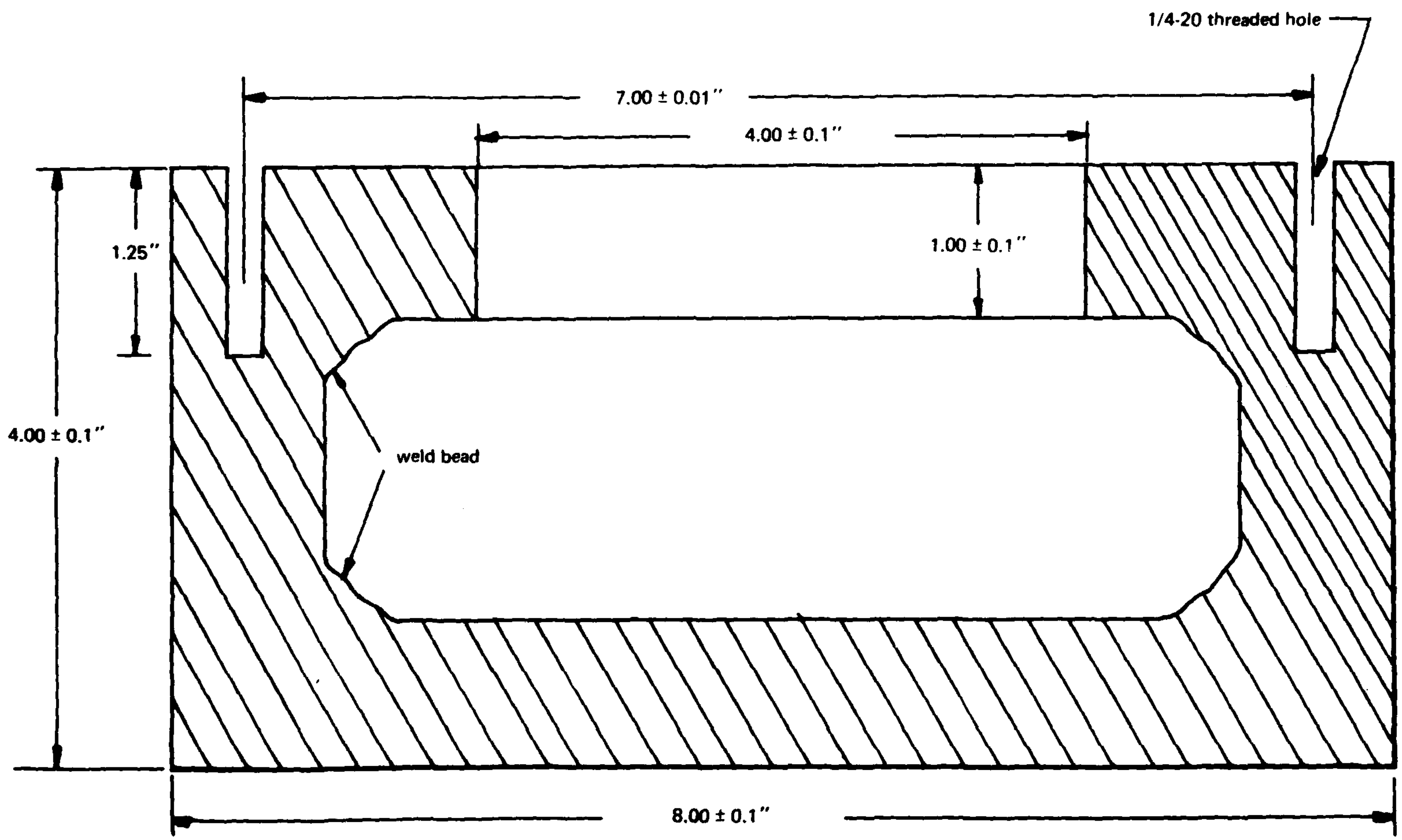

Figure 2. Seal test jig bottom for flat flange seal systems (cross section).

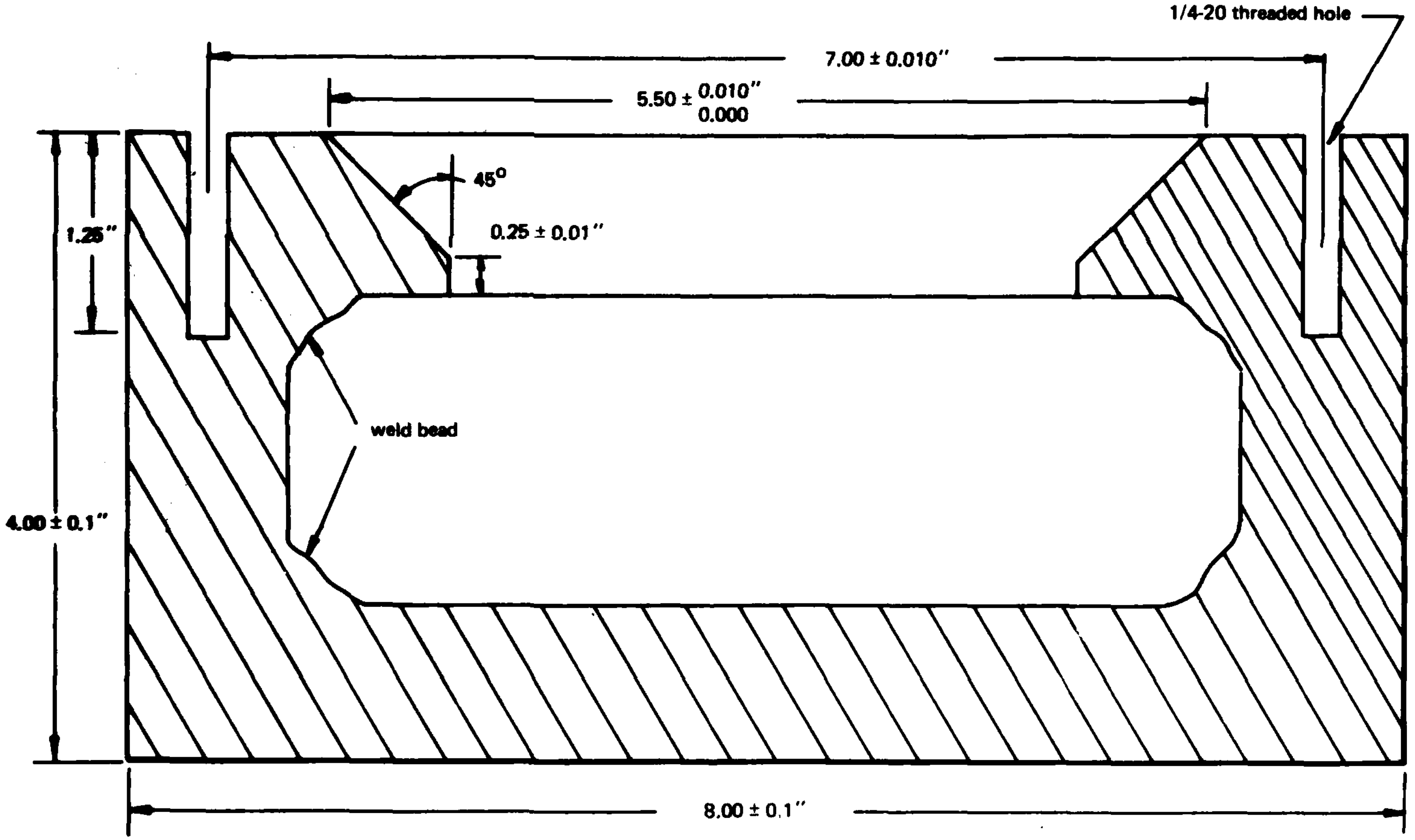

Figure 3. Seal test jig bottom for angular flange seal systems (cross section).

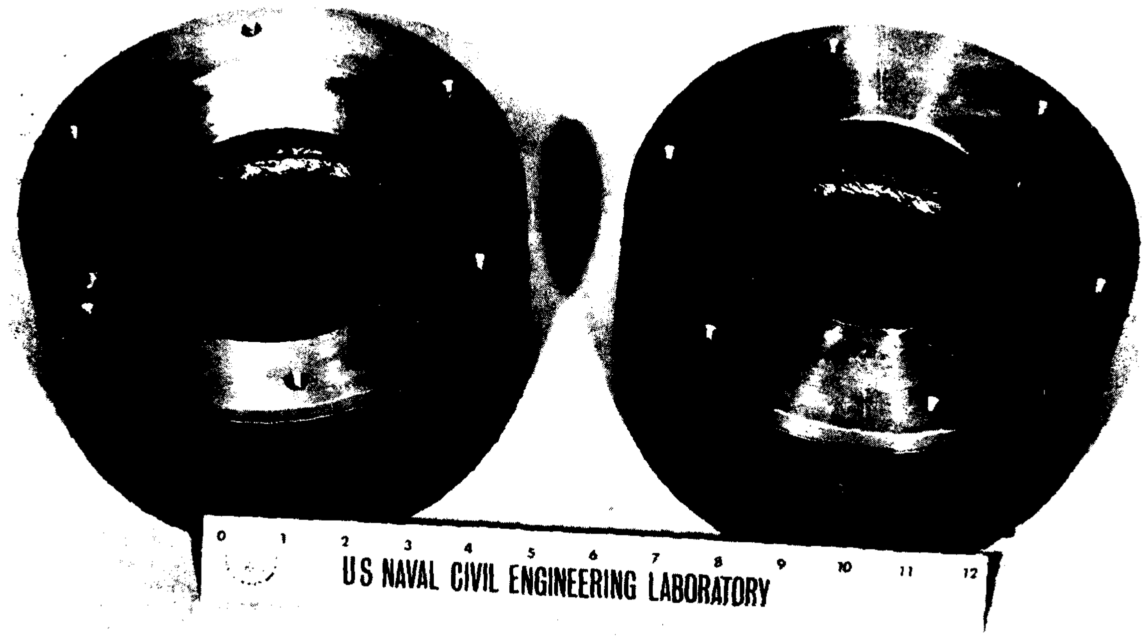

Figure 4. Seal test jig bottoms. Angular flange on left, flat flange on right.

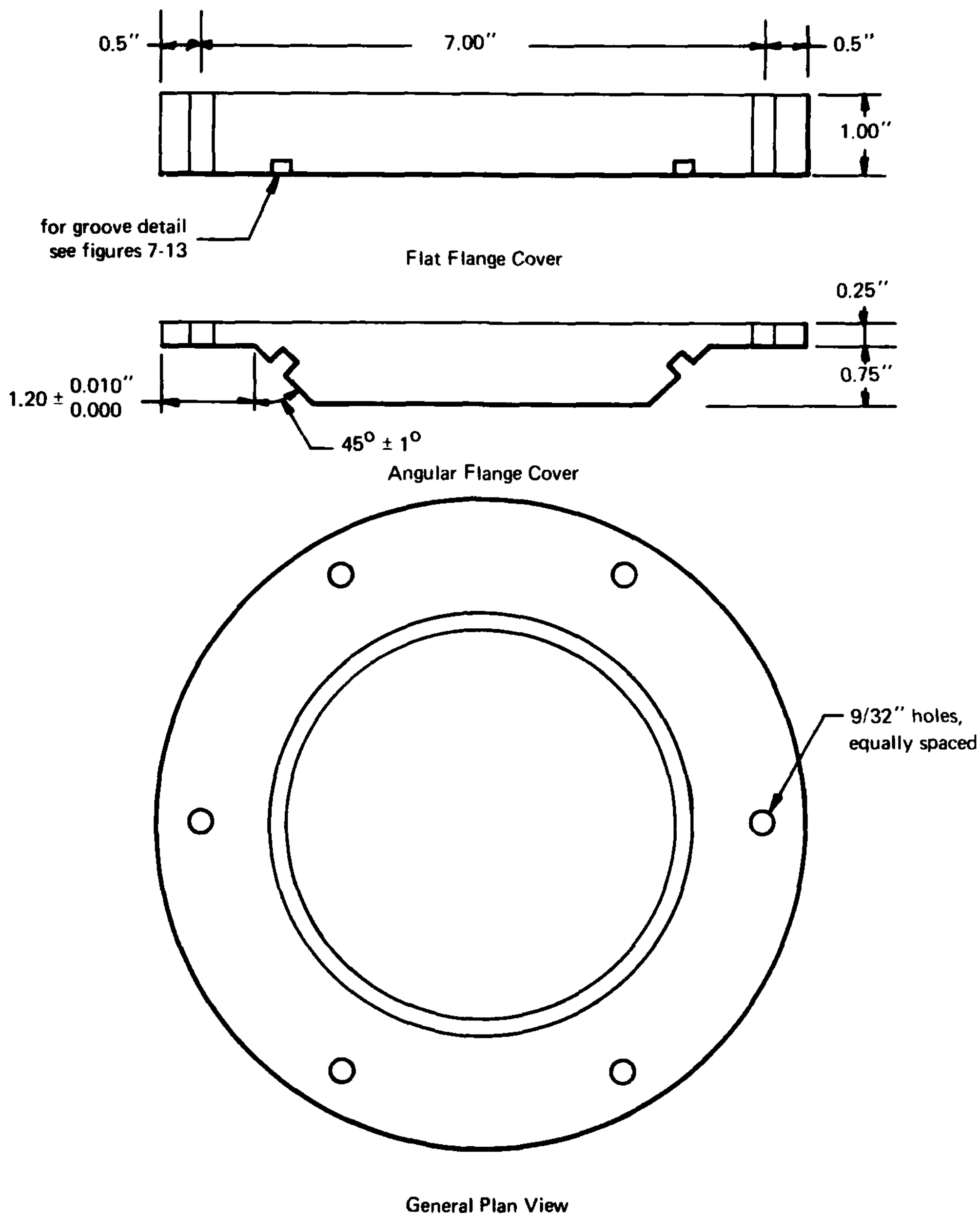

Figure 5. Seal test jig covers.

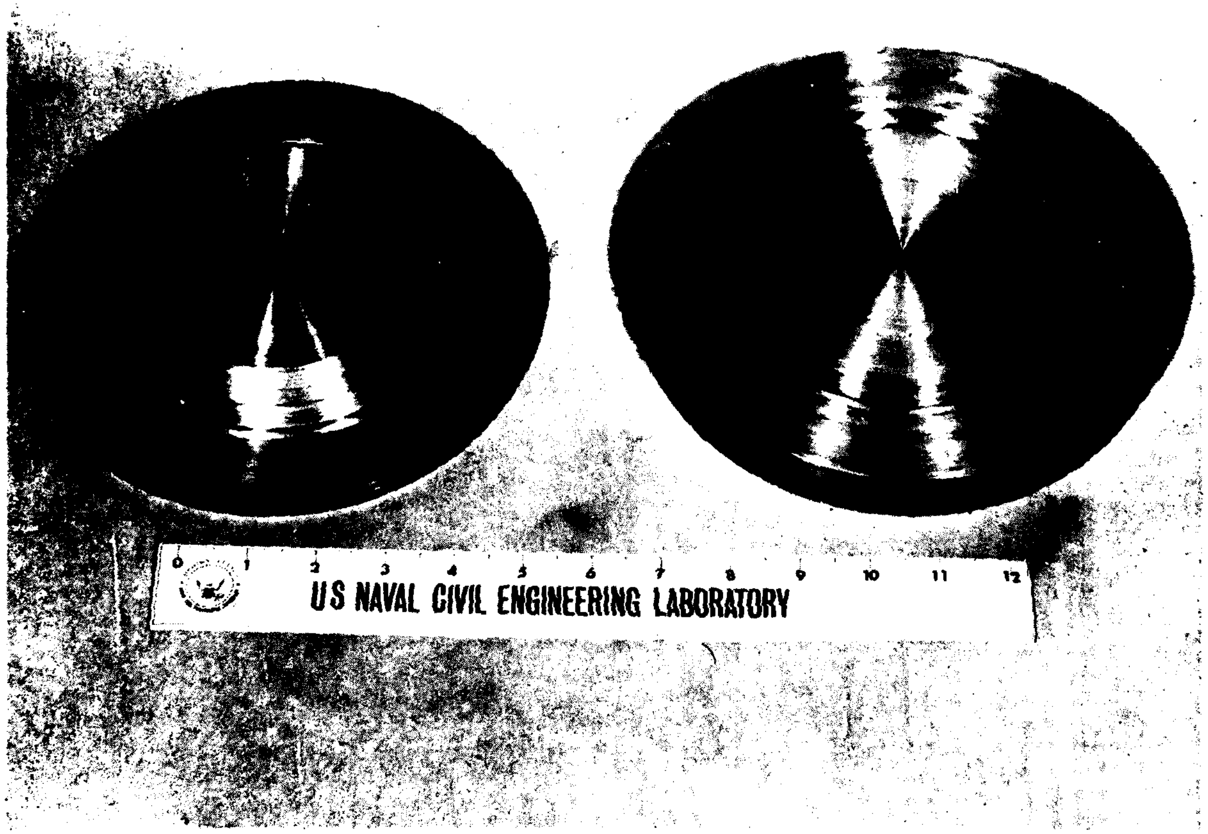

Figure 6. Seal test jig covers. Angular flange on left, flat flange on right.

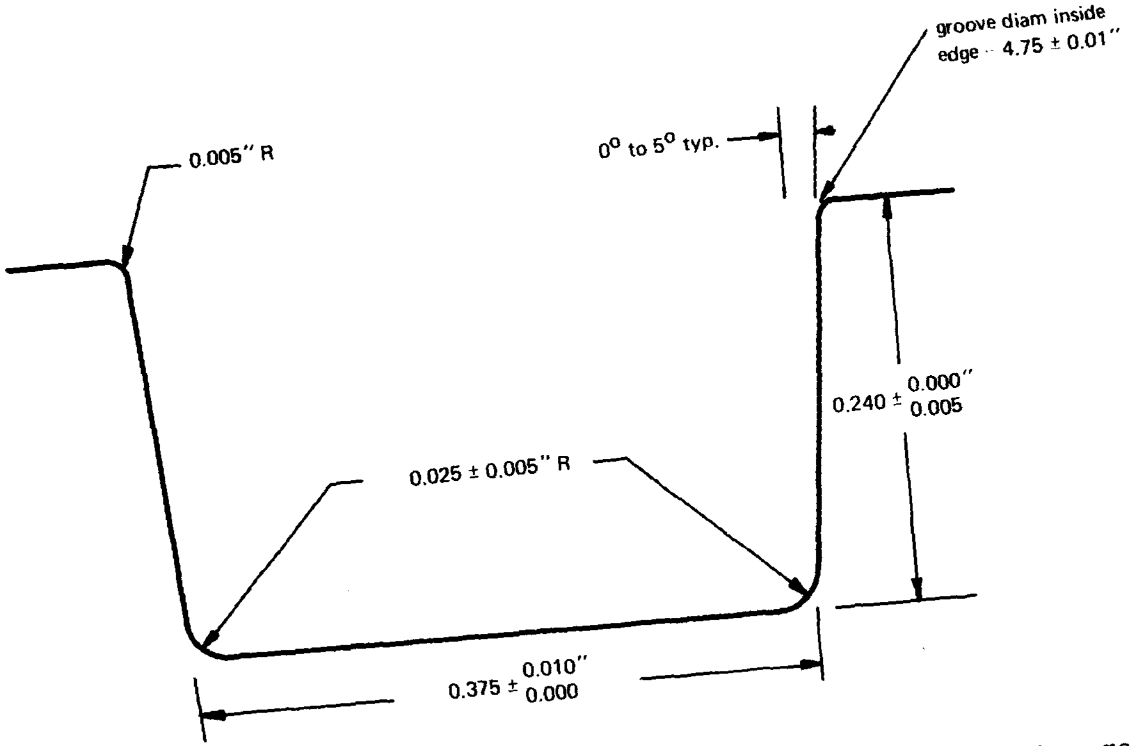

Figure 7. Groove configuration for O-rings, lobed rings, and lip seals in a rectangular groove-flat flange seal system.

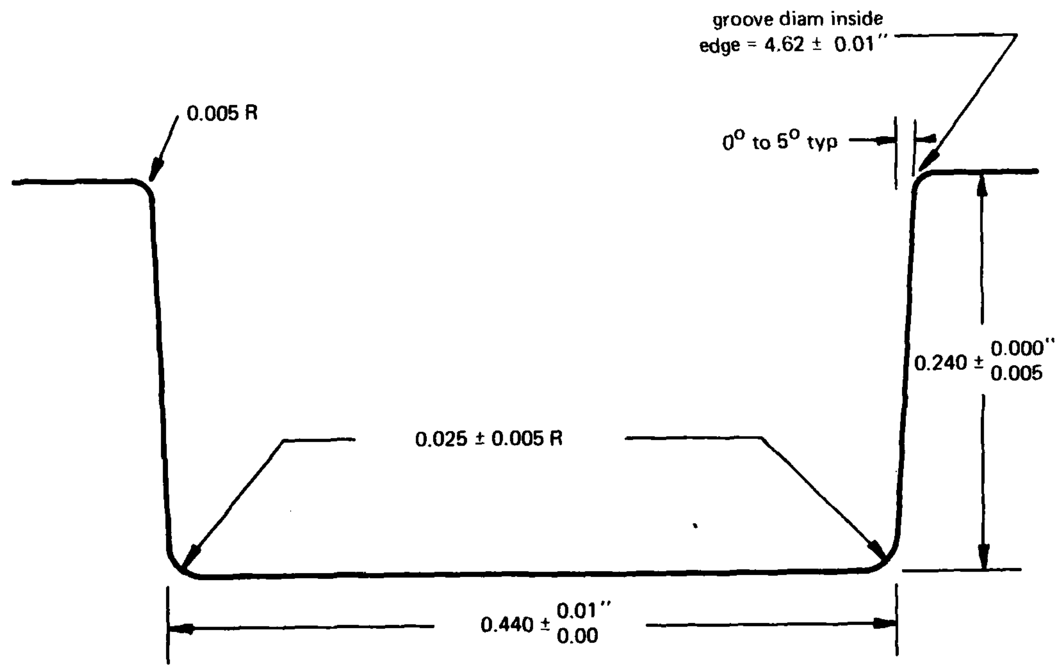

Figure 8. Groove configuration for O-rings and lobed rings with anti-extrusion devices in rectangular groove O-ring systems.

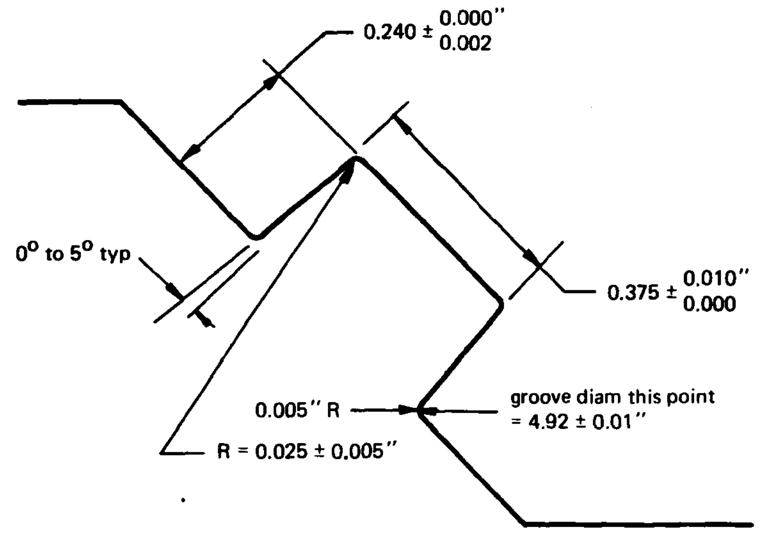

Figure 9. Groove configuration for O-rings, lobed rings and lip seals in rectangular groove-angular flange seal systems.

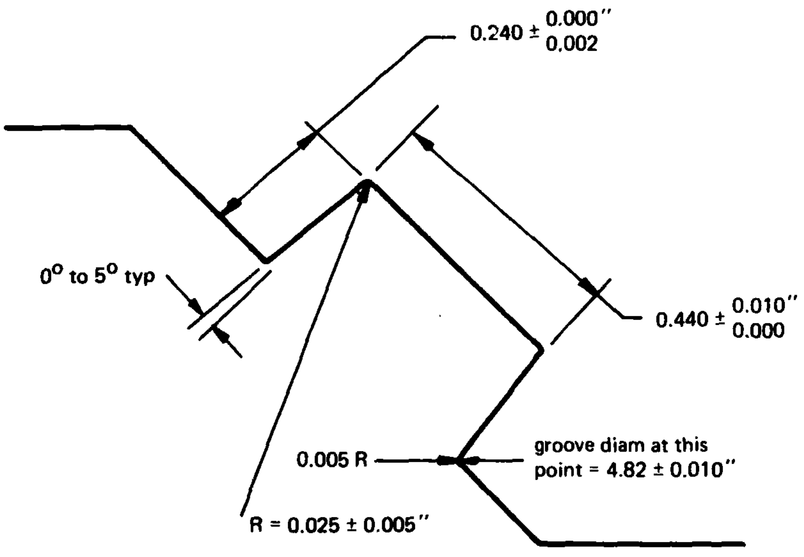

Figure 10. Groove configuration for O-rings, and lobed rings with anti-extrusion devices in rectangluar groove-angular flange seal systems.

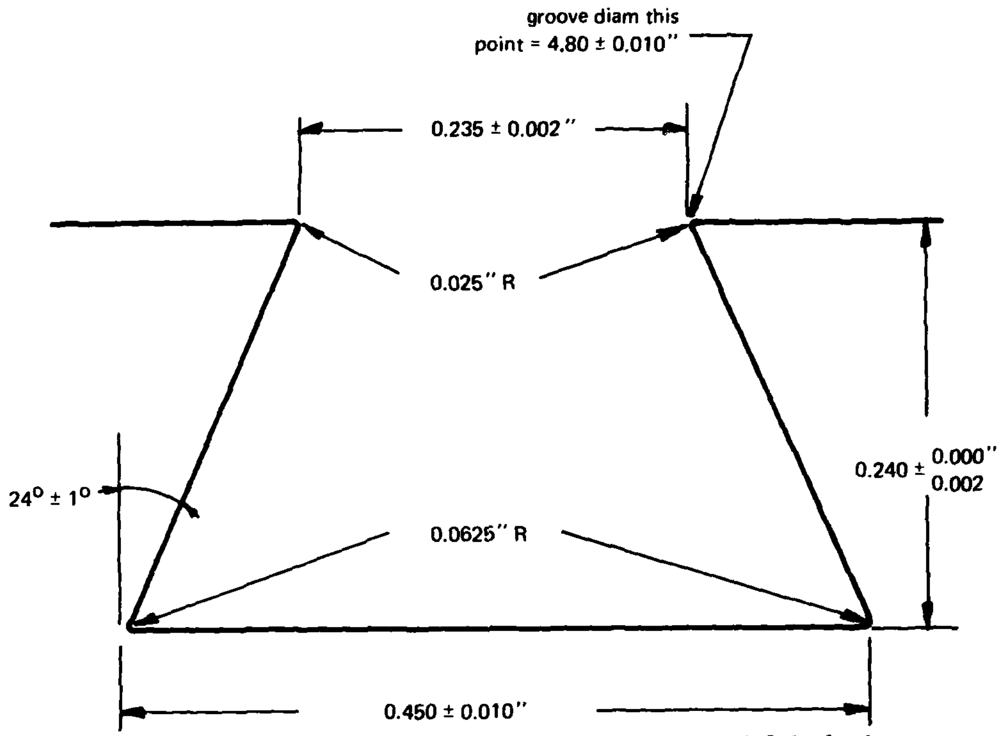

Figure 11. Groove configuration for O-rings, and lobed rings in dovetail groove-flat flange seal systems.

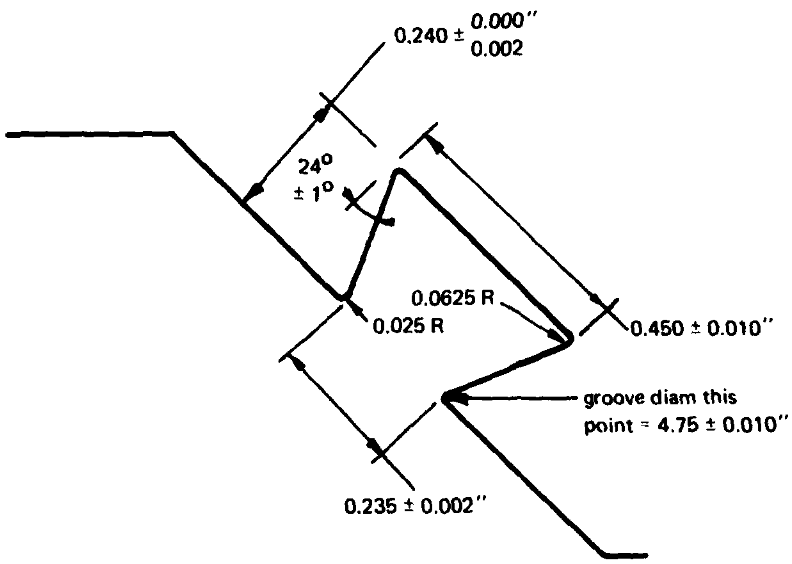

Figure 12. Groove configuration for O-rings and lobed rings in dovetail groove-angular flange seal systems.

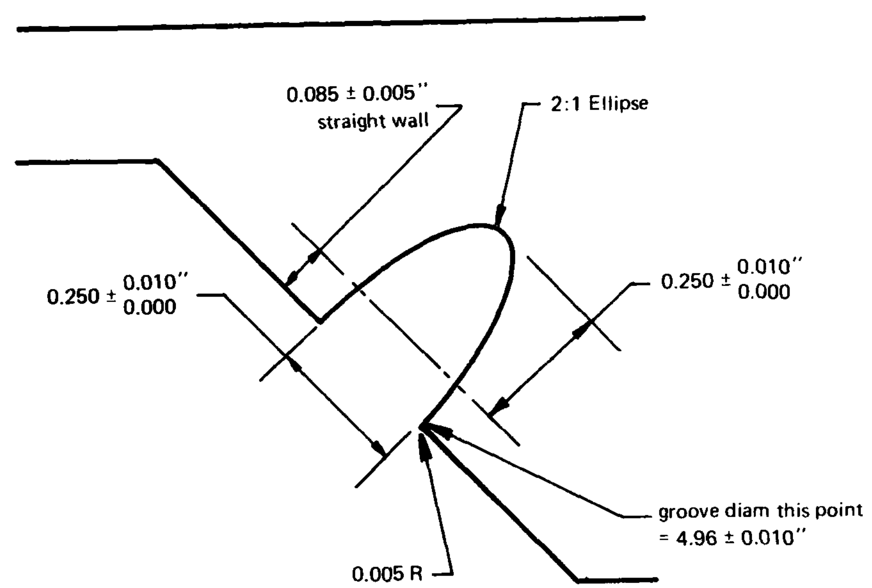

Figure 13. Groove configuration for O-rings in eliptical groove-angular flange seal systems.

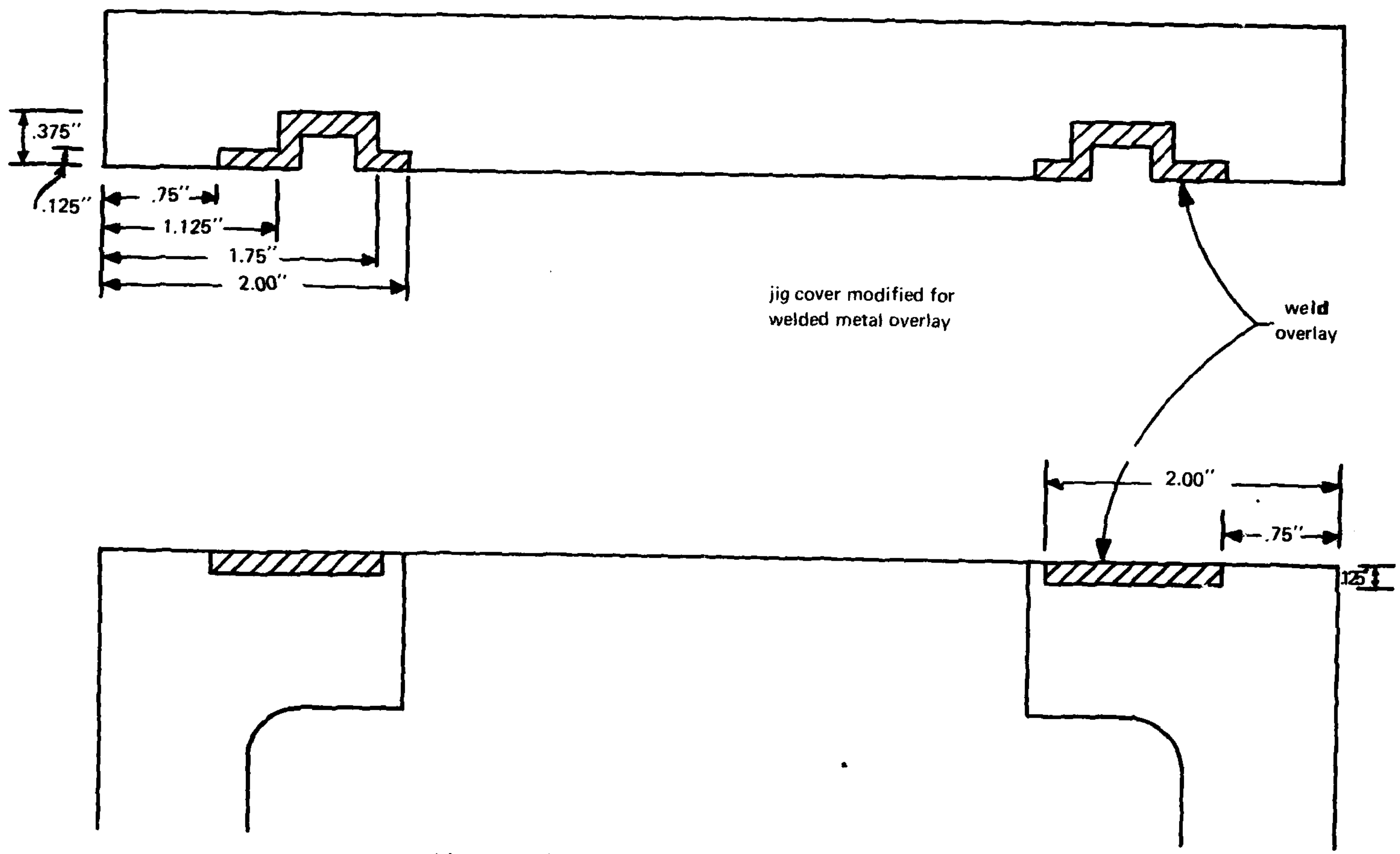

Figure 14. Jig bottom modified for welded metal overlay.

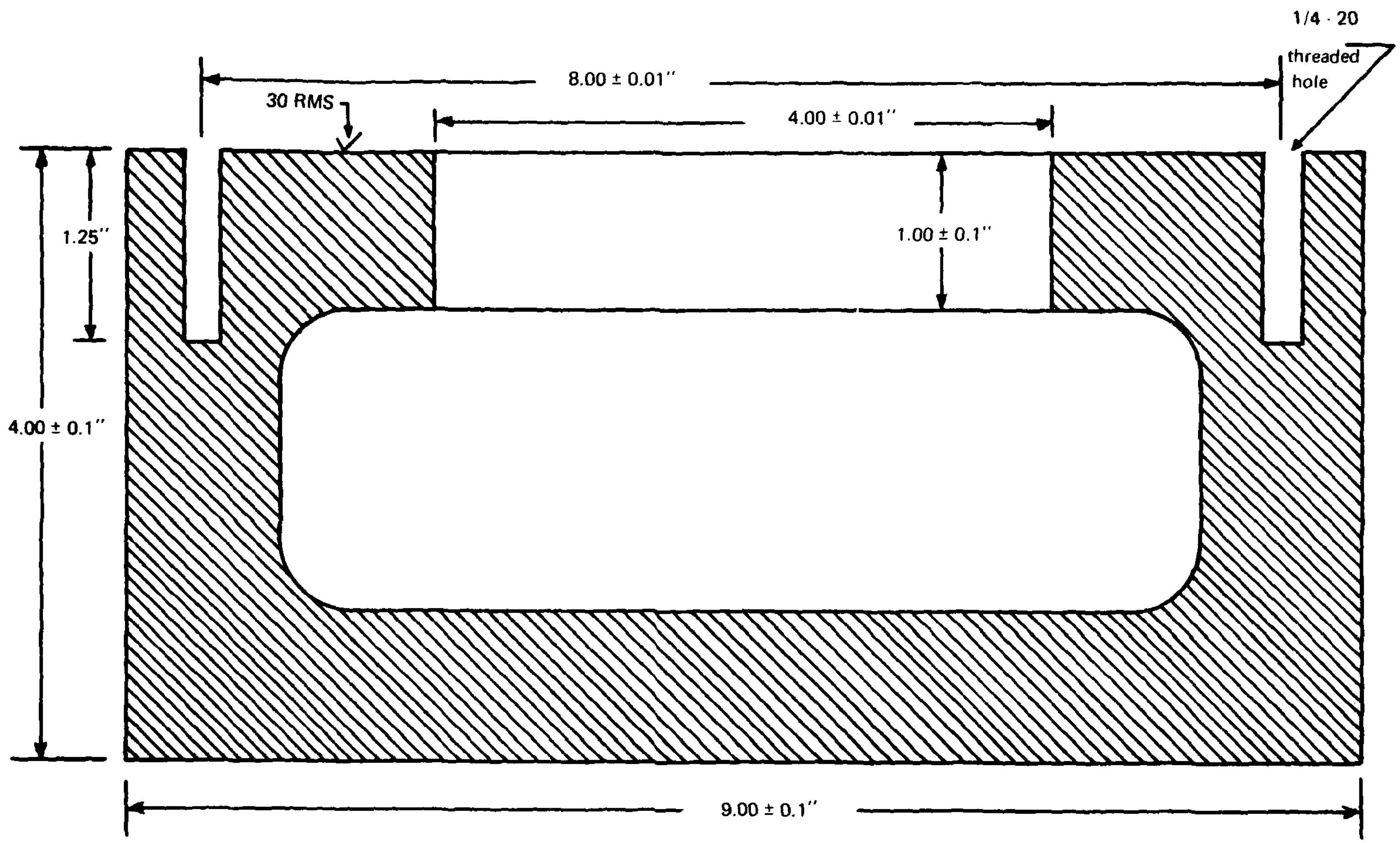

Figure 15. Jig bottom for flat top-aluminum (cross section).

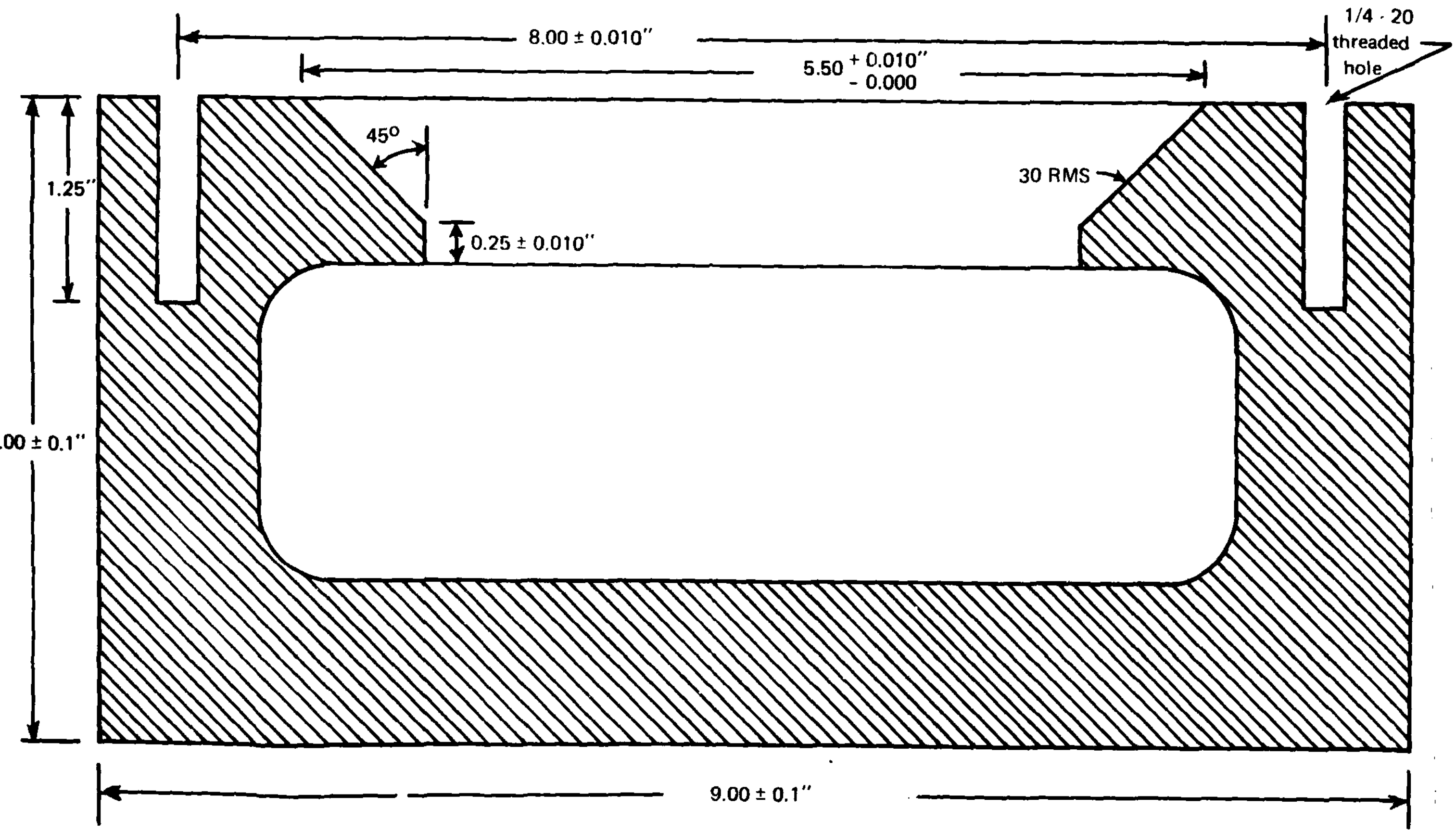

Figure 16. Jig bottom for angular top-aluminum (cross section).

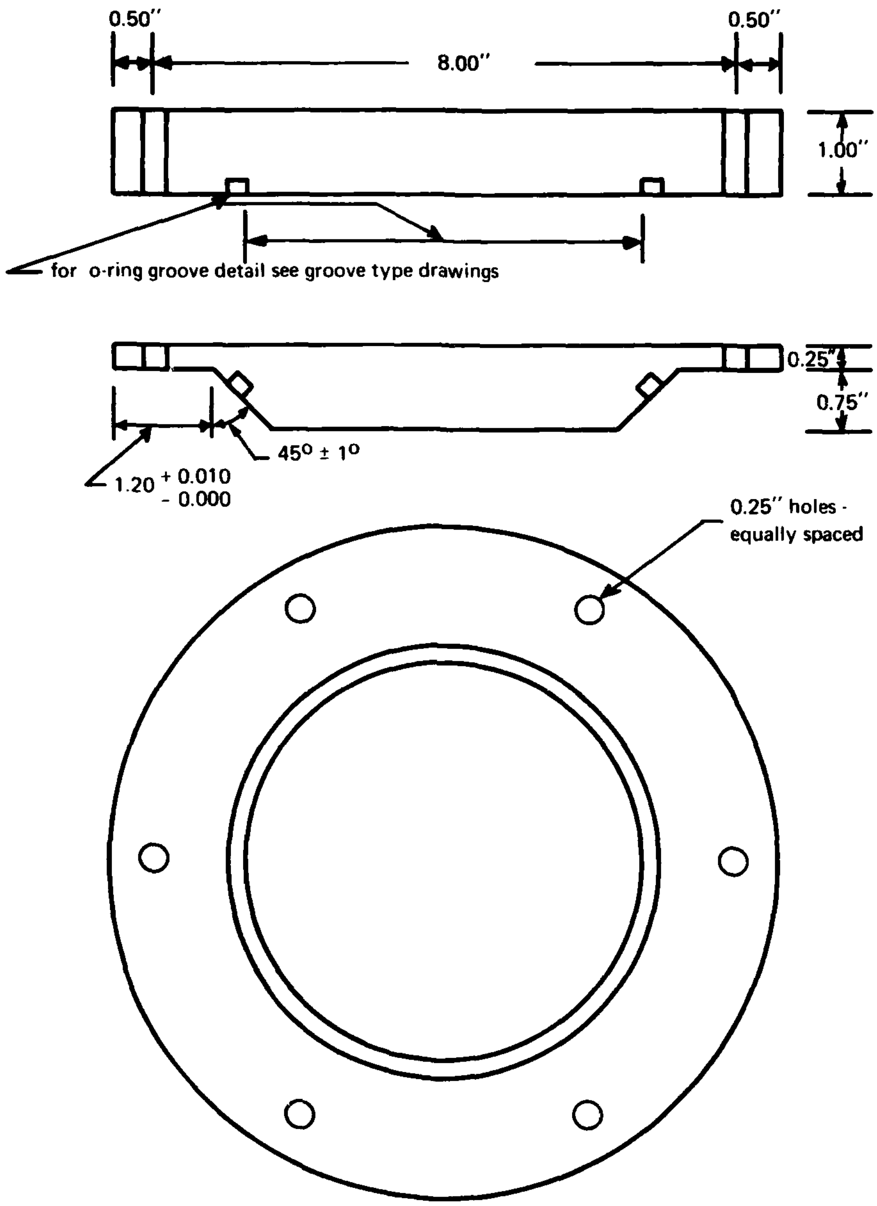

Figure 17. Test jig top - aluminum.

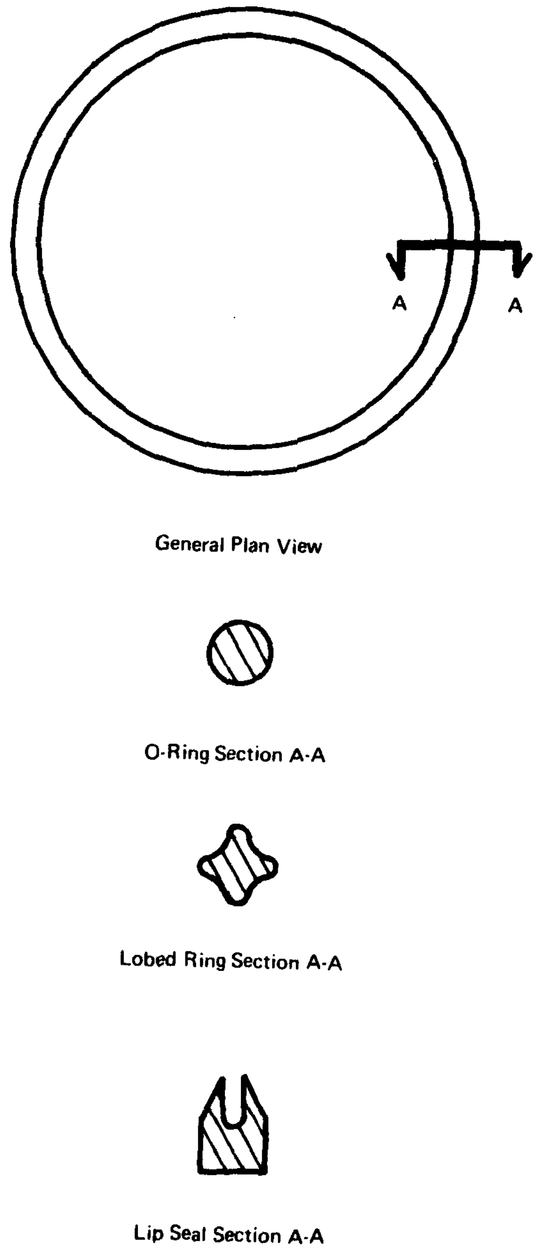

Figure 18. Elastomeric seal models.

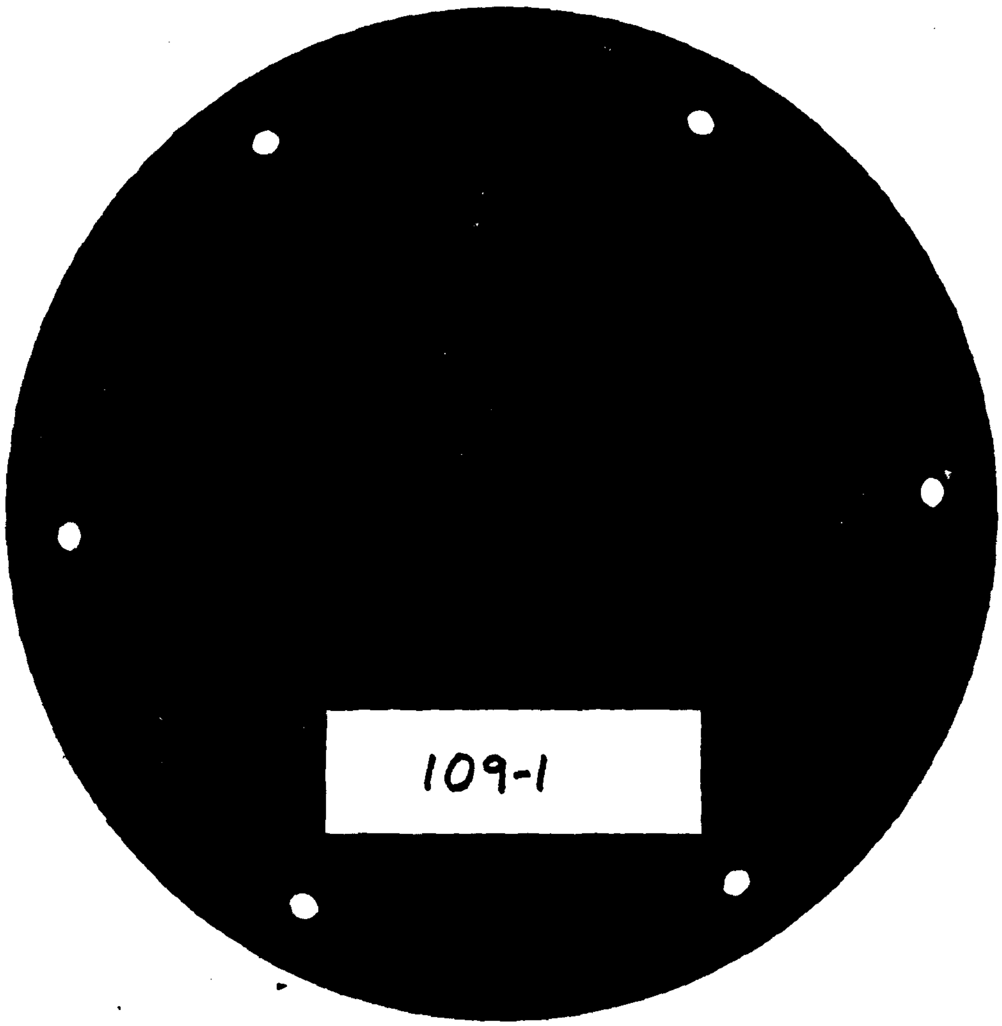

Figure 19. Carbon steel seal test jig without anode after recovery showing flaky red rust.

Figure 20. Carbon steel seal test jig with anode after recovery. Showing thin rust on the seal jig and white corrosion products on the anode.

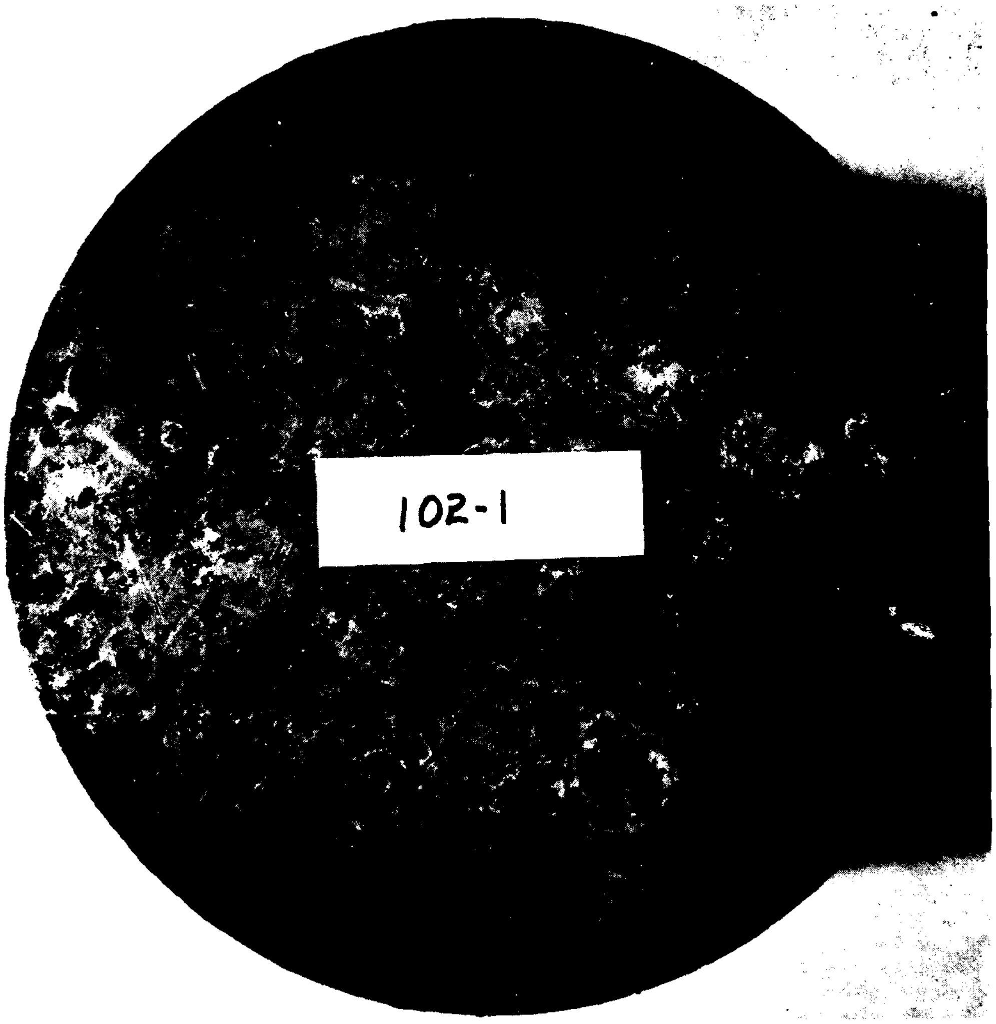

Figure 21. View of bottom of aluminum seal test jig without anode after recovery showing corrosion pits.

Figure 22. View of top of aluminum seal test jig with anode after recovery showing thick white corrosion products on the anode.

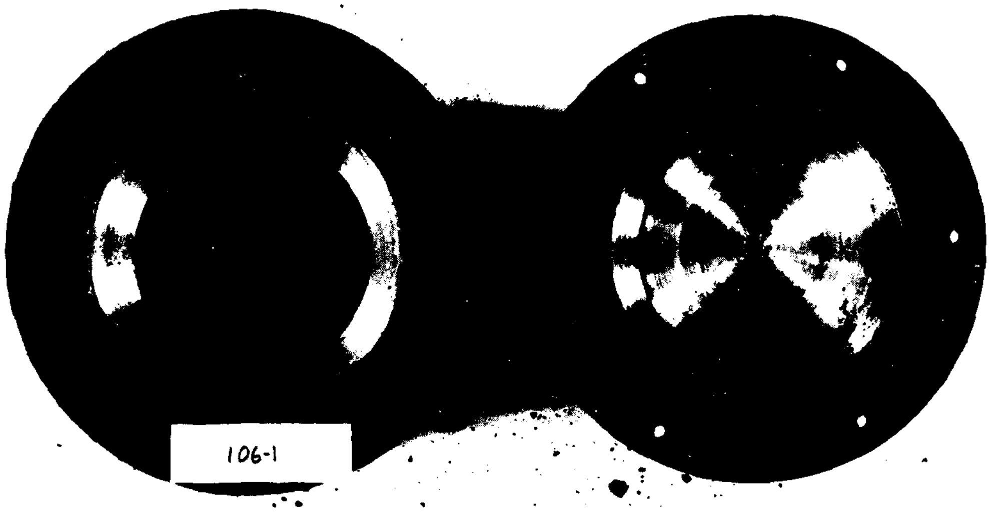

Figure 23. Carbon steel-angular flange test jig without anode after exposure showing corrosion of flange to seal.

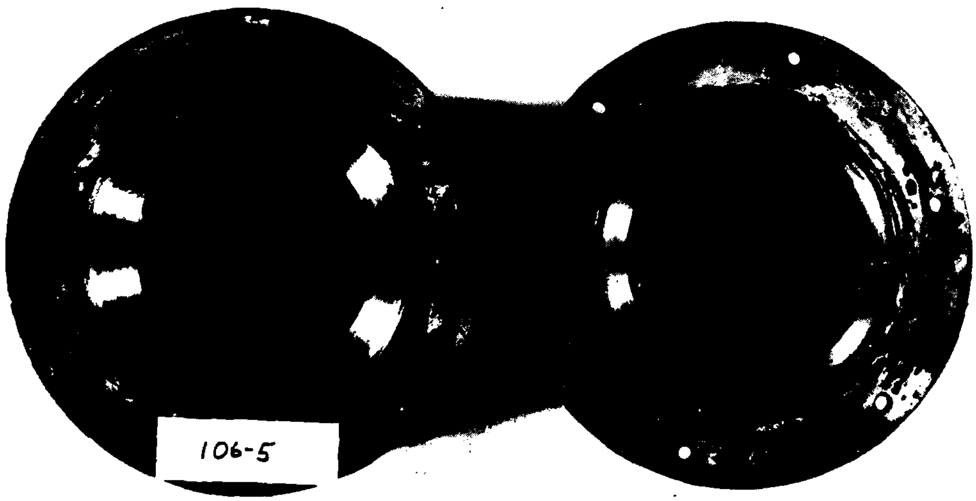

Figure 24. Carbon steel-angular flange test jig with anode after exposure showing corrosion of flange to seal.

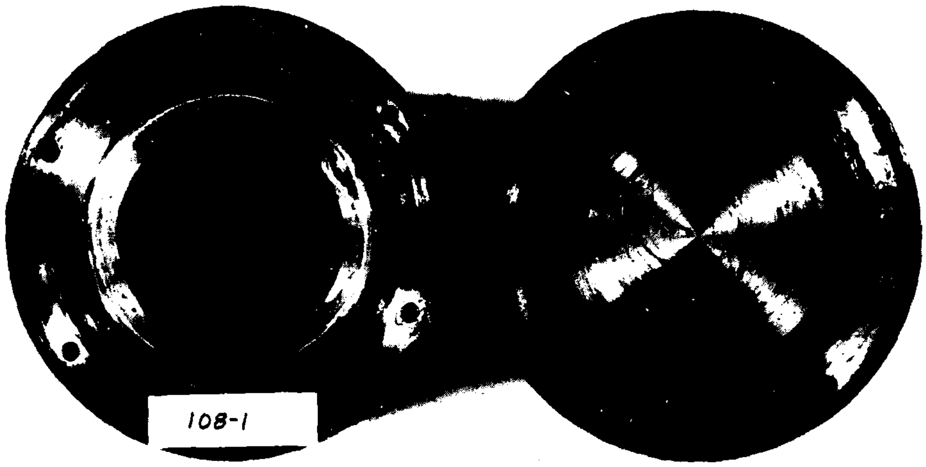

Figure 25. Carbon steel-flat flange test jig without anode after exposure showing corrosion of flange to seal.

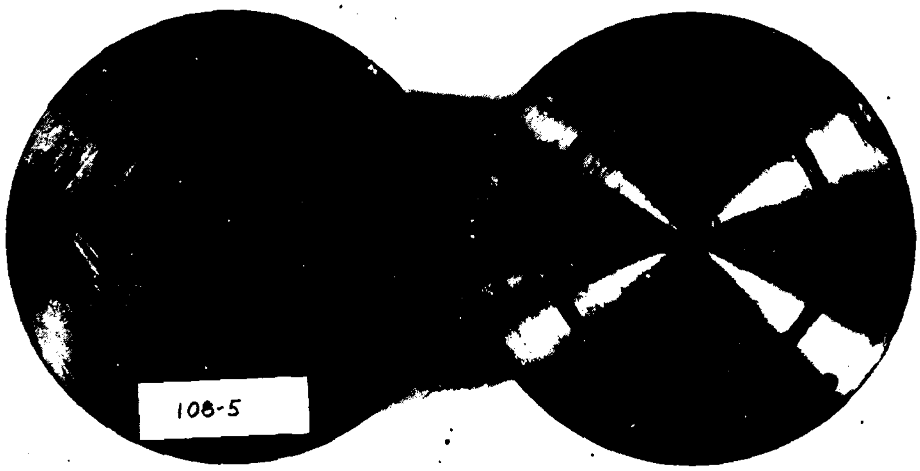

Figure 26. Carbon steel-flat flange test jig with anode after exposure showing corrosion of flange to seal.

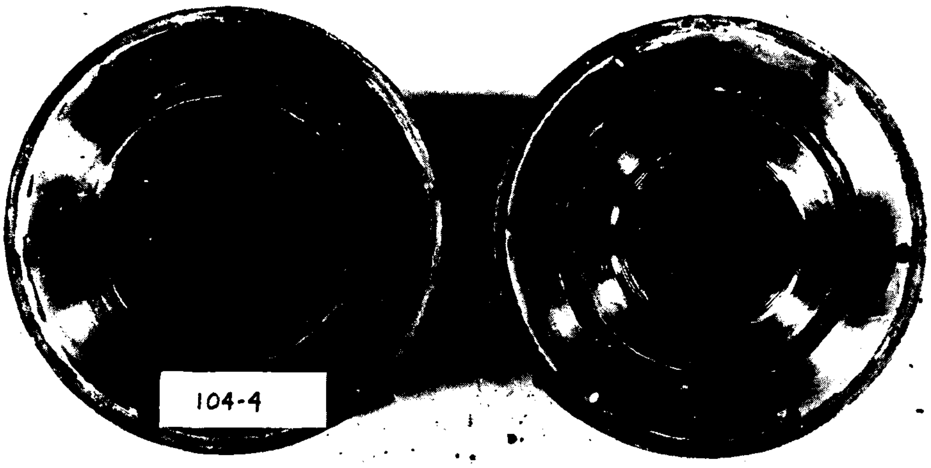

Figure 27. Carbon steel flat flange test jig with corrosion resistant metal overlay without anode after exposure showing lack of corrosion on overlay.

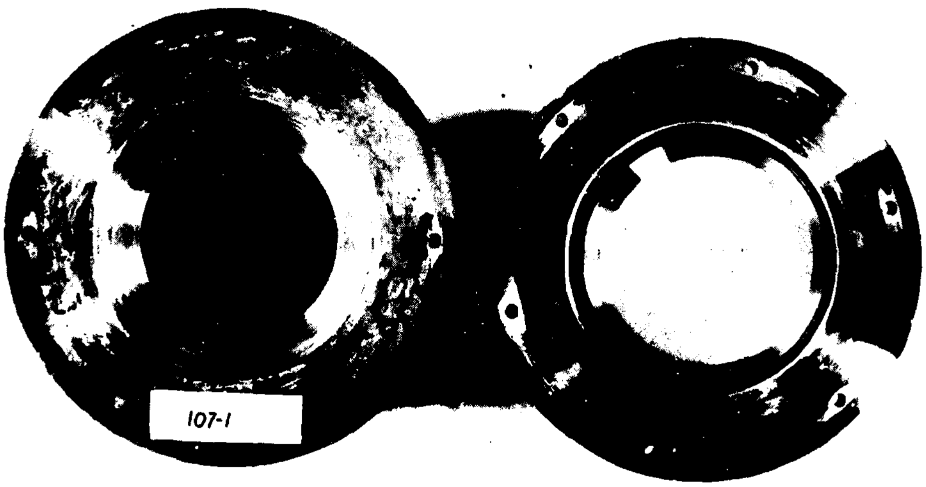

Figure 28. Aluminum angular flange test jig without anode after exposure showing corrosion of flange to seal.

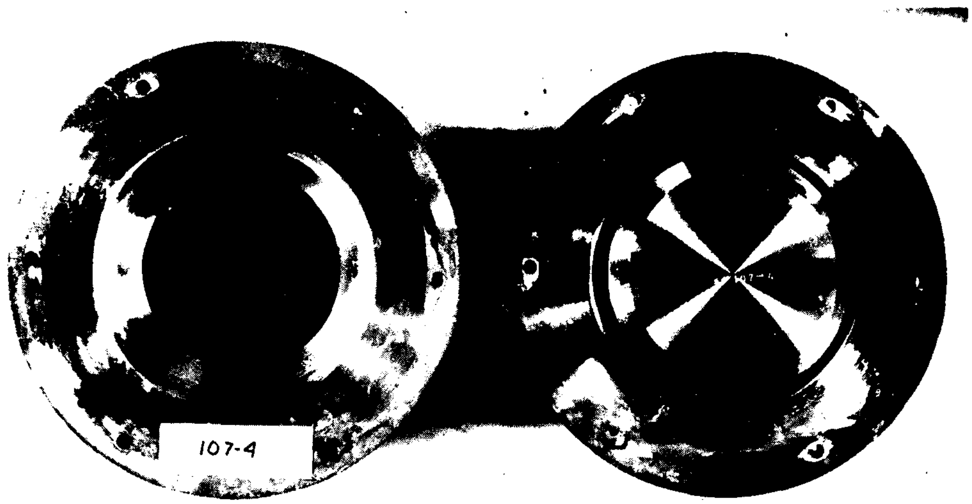

Figure 29. Aluminum angular flange test jig with anode after exposure showing corrosion of flange to seal.

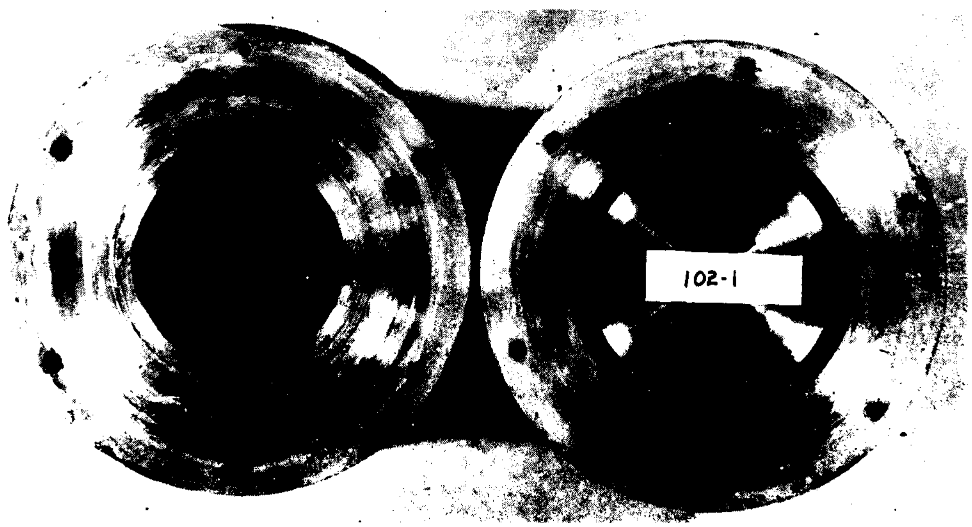

Figure 30. Aluminum flat flange test jig without anode after exposure showing corrosion of flange to seal.

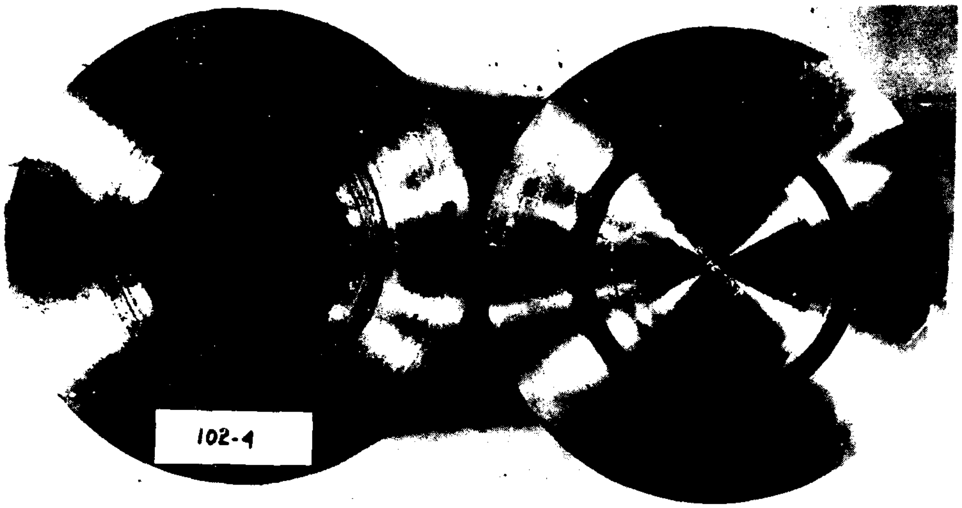

Figure 31. Aluminum-flat flange test jig with anode after exposure showing corrosion of flange to seal.

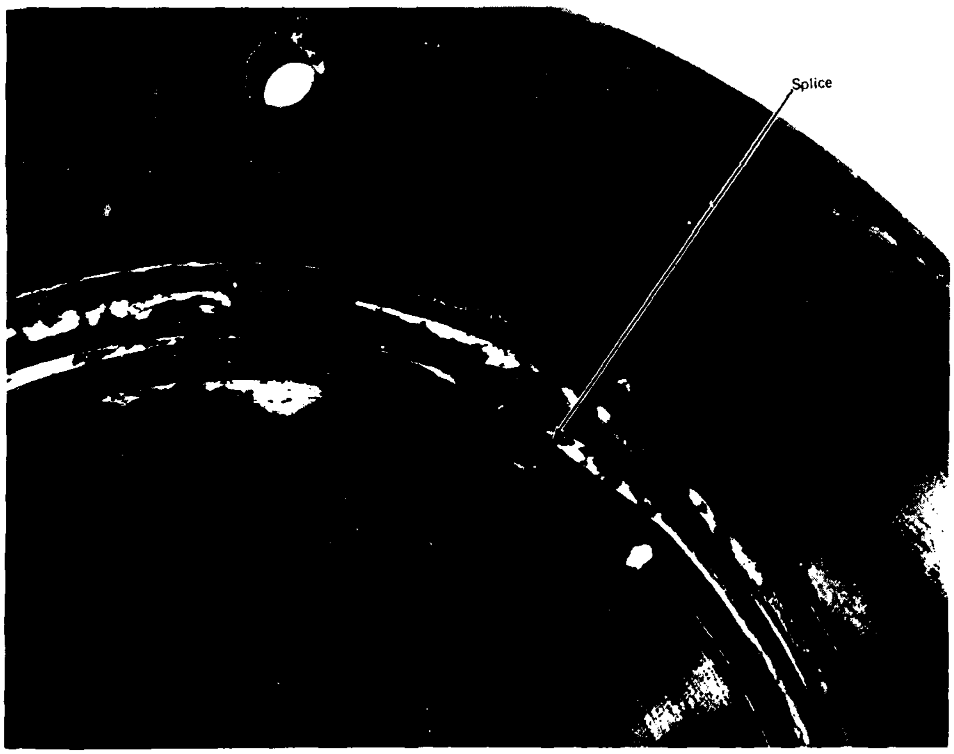

Figure 32. Failure of elastomeric back-up ring at splice.

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13. ABSTRACT

Long term effects of hydrospace on seals and gaskets are under investigation at NCEL (Naval Civil Engineering Laboratory). Phase III includes the evaluation of fifteen seal systems and five metallic seal flange materials after exposure to the marine environment for 189 days at a depth of 5,900 feet in the Pacific Ocean.

No seal failures due to flange corrosion or seal deterioration were noted. Galvanic anodes reduced flange corrosion. Corrosion resistant metal overlays prevented flange corrosion.

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Underwater environments						
Deep ocean vehicles						
Hydrostatic pressure						
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Metallic seals						
Performance tests						
Corrosion prevention						